S4-20

Appendix G N92-10048 p. 13

SPACE PROPULSION TECHNOLOGY DIVISION

NASA Lewis Research Center

MPD THRUSTER TECHNOLOGY

ROGER M. MYERS

SVERDRUP TECHNOLOGY
NASA LEWIS RESEARCH CENTER

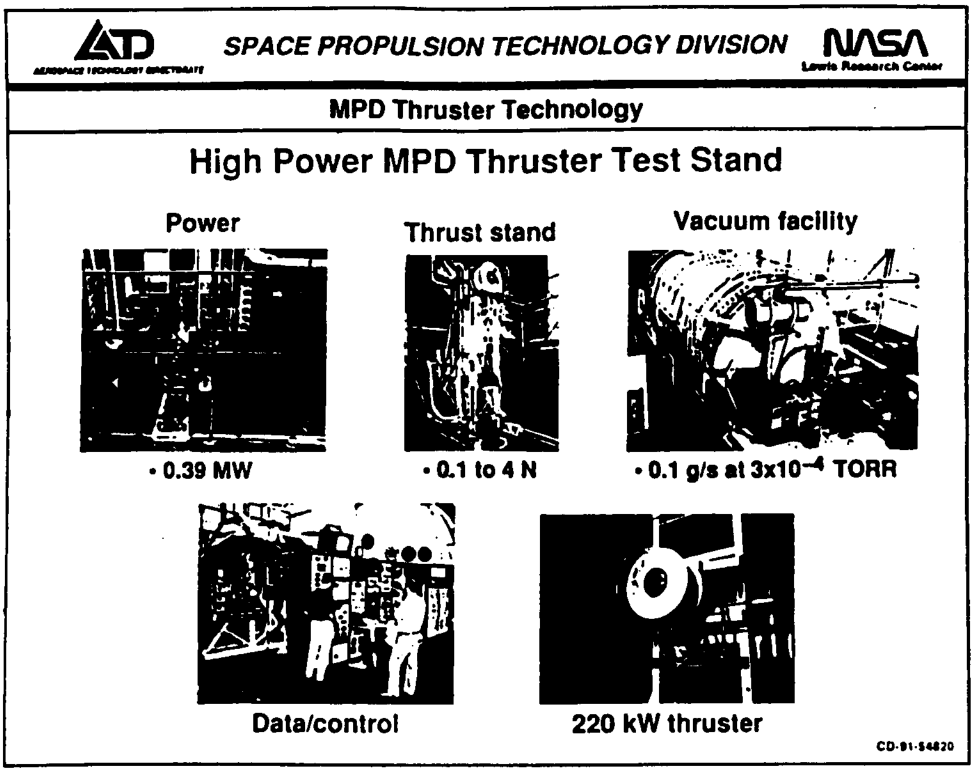
MAY 16, 1991

SPACE PROPULSION TECHNOLOGY DIVISION

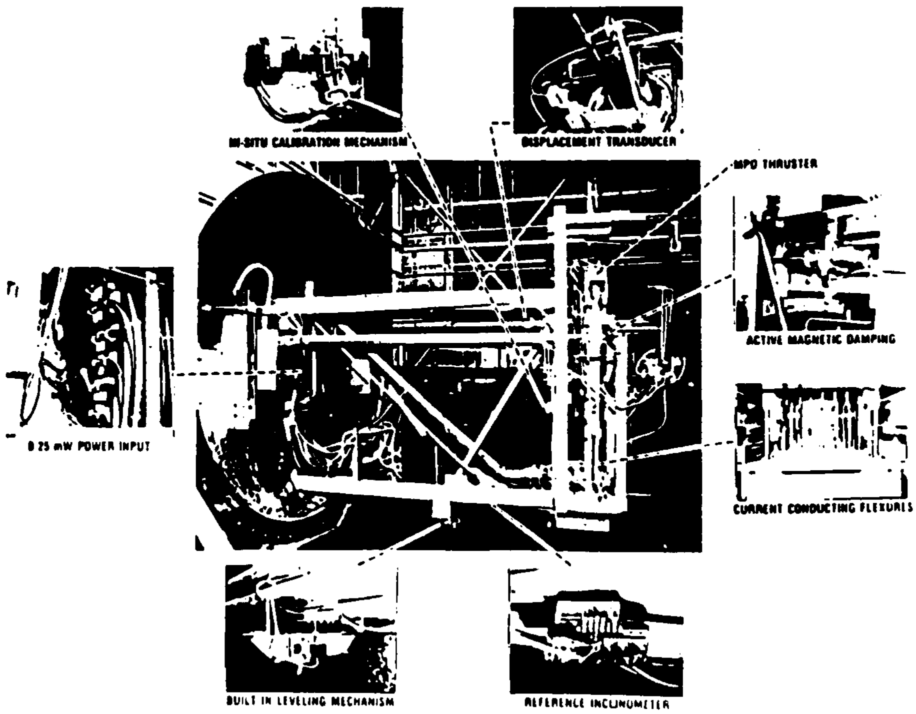
NASA Lewis Research Center

IN-HOUSE PROGRAM OVERVIEW

- RE-ESTABLISHED IN 1987
- FOCUSSED ON STEADY-STATE THRUSTERS AT POWERS < 1 MW
- DEVELOPED PERFORMANCE MEASUREMENT AND DIAGNOSTICS TECHNOLOGIES FOR HIGH POWER THRUSTERS
- DEVELOPING MHD CODE
- GOALS ARE TO ESTABLISH
  - PERFORMANCE AND LIFE LIMITATIONS
  - INFLUENCE OF APPLIED FIELDS
  - PROPELLANT EFFECTS
  - SCALING LAWS



MPD THRUSTER TEST STAND

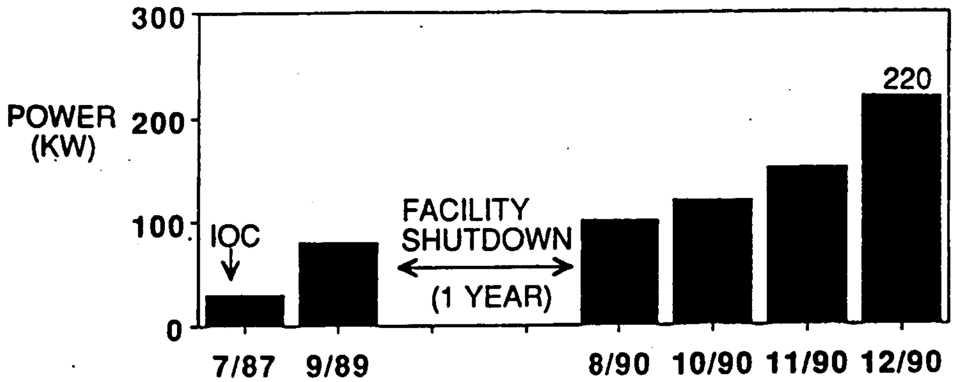


SPACE PROPULSION TECHNOLOGY DIVISION

NASA Lewis Research Center

HIGH POWER ELECTRIC PROPULSION (MPD)

DEMONSTRATED MPD THRUSTER POWER



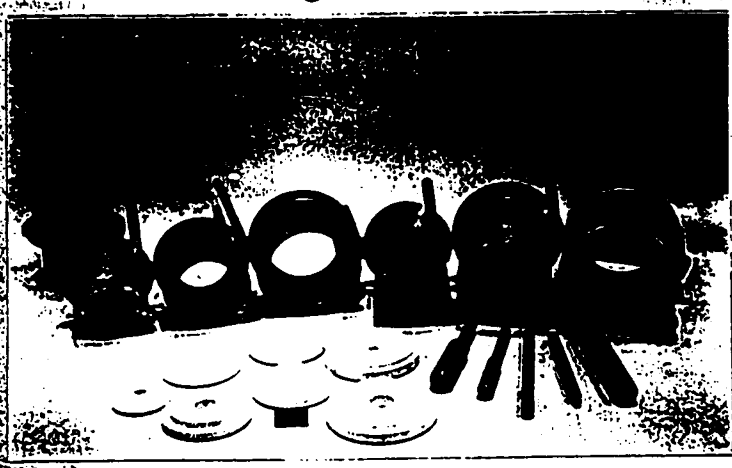
DEMONSTRATED MPD THRUSTER POWER INCREASING RAPIDLY

SPACE PROPULSION TECHNOLOGY DIVISION

NASA

MPD Thruster Technology

Thruster Scaling and Materials Effects



- 2, 3 and 4 inch diameter anodes both 3 and 6 inches long
- 0.5 and 1 inch diameter cathodes
- 2% Th and BaO impregnated tungsten cathodes

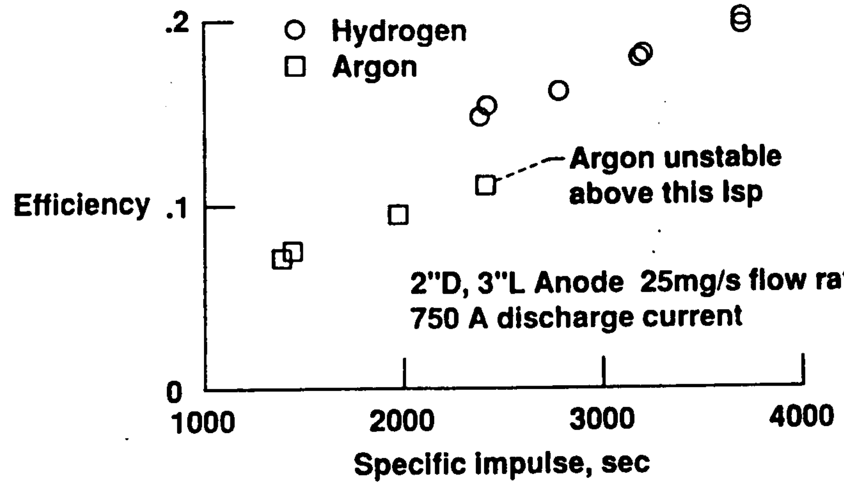
CD-91-54832

SPACE PROPULSION TECHNOLOGY DIVISION

Lewis Research Center

MPD Thruster Technology

Performance Measured With Hydrogen and Argon



Performance dramatically improved with hydrogen
- Efficiency increased by 2X
- I_{SP} increased by 50%

CD-91-54824

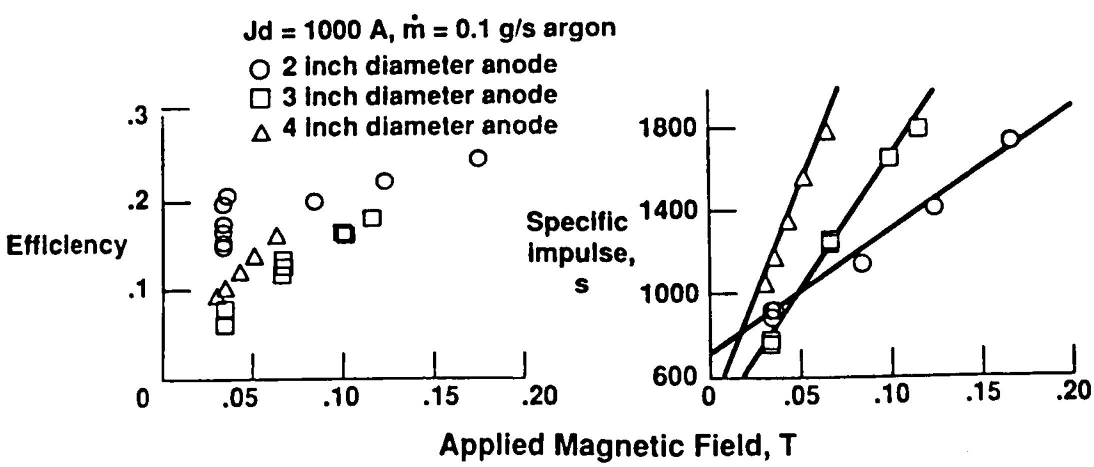
SPACE PROPULSION TECHNOLOGY DIVISION

Lewis Research Center

MPD Thruster Technology

Thruster Performance

Geometry and Applied Field Effects



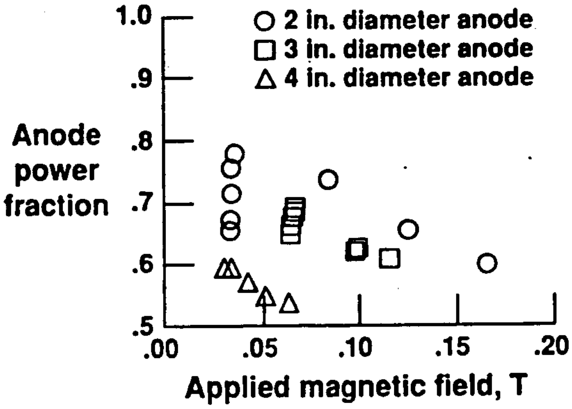
- Efficiency increases with applied field strength
- Specific impulse increases with both anode radius and applied field strength

CD-91-54823

MPD Thruster Technology

Anode Power Deposition

Applied Field and Geometry Effects



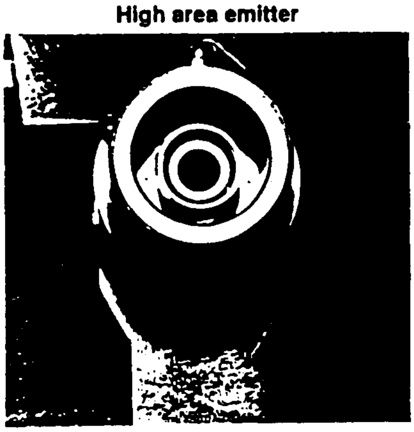
Increasing applied field strength and anode diameter decrease anode power fraction

CD-91-54825

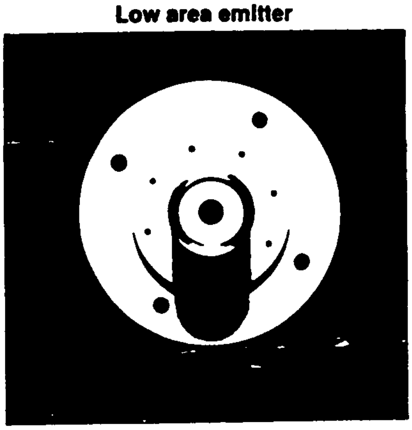
HIGH POWER ELECTRIC PROPULSION (MPD)

MPD THRUSTER HIGH CURRENT HOLLOW CATHODE TECHNOLOGY

High area emitter



Low area emitter



Three hollow cathode assemblies fabricated and prepared for evaluation

CD-90-51136

ATD AEROSPACE TECHNOLOGY DIRECTORATE — SPACE PROPULSION TECHNOLOGY DIVISION — NASA Lewis Research Center

MPD Thruster Technology

Scaling Issues

- Megawatt class operation required for missions of interest
- Cannot operate megawatt class steady-state in current facilities
- Must be able to correlate MW class pulsed thruster operation and steady state data
- Data must enable rational extrapolation to high power levels

How do we realistically study MPD thruster performance and life using currently available facilities?

CD-91-54828

ATD AEROSPACE TECHNOLOGY DIRECTORATE — SPACE PROPULSION TECHNOLOGY DIVISION — NASA Lewis Research Center

MPD Thruster Technology

Diagnostics

- X-Y probe positioning stand
  - Electrostatic probes
  - enclosed current contours
  - Axial applied B field distribution
- Plume imaging
  - Correlate ion density distribution with applied field
- Spectoscopy
  - Non-invasive temperature and density measurements

CD-91-54829

MPD Thruster Modeling

Program Outline

Conservation of mass → density (ρ)
Conservation of momentum → velocity (V_r, V_θ, V_z)
Conservation of energy → temperature (T)
Equation of state → pressure (P)
Evaluate transport coeffs, hall parameters, etc...

Fluid loop

Ohm's law and maxwell equations → induced fields (B_θ)
Maxwell (Ampere's) equation → current density (j)
Ohm's law → electric field (E → plasma potential)
evaluate energy source, sink terms, etc...

Field loop

Convergence on exhaust velocity $V_{ex}^{new} \le 0.01\, V_{ex}^{old}$,
plasma potential: $\Phi_{new} \le 0.01 \Phi_{old}$)

No

Yes → Evaluate thrust, specific impulse, efficiency,...
Write to data files
Done

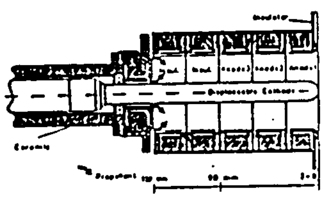
CD-91-54837

AEROSPACE TECHNOLOGY DIRECTORATE
SPACE PROPULSION TECHNOLOGY DIVISION
NASA Lewis Research Center

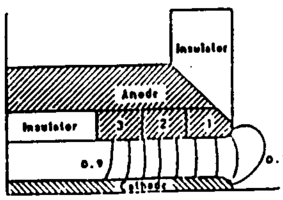
MPD Thruster Modeling

Comparison With U. Stuttgart Model/Experiment

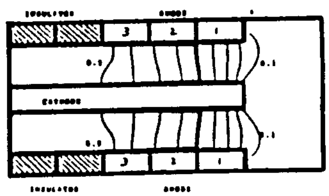
(6kA, 6 g/s)



Stuttgart-experiment



Stuttgart-model



NASA LeRC-model

Current fractions into anode segments

Segment 1:	46%	44%	51%
Segment 2:	27%	27%	22%
Segment 3:	27%	29%	27%

NASA LeRC code in agreement with Stuttgart MPDT experiment/model

CD-91-54839

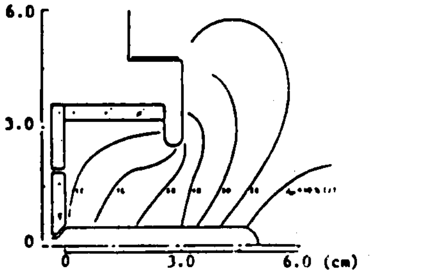
SPACE PROPULSION TECHNOLOGY DIVISION

AEROSPACE TECHNOLOGY DIRECTORATE — NASA Lewis Research Center

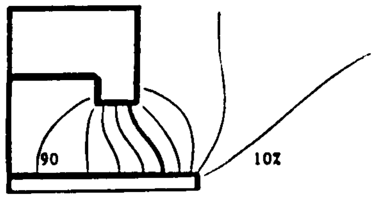
MPD Thruster Modeling

Comparison with Princeton University

Half-Scale Benchmark Thruster

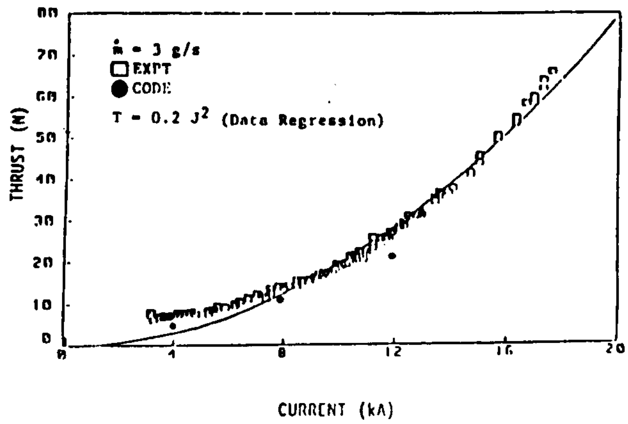


ENCLOSED CURRENT CONTOURS (MEASURED)
12.4 kA, 1.5 g/s, QUASI-STEADY OPERATION



ENCLOSED CURRENT CONTOURS (PREDICTED)
12.4 kA, 1.5 g/s, STEADY-STATE OPERATION

Thrust Characteristics



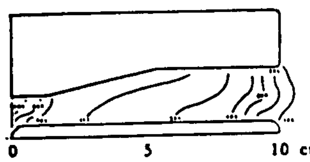
SPACE PROPULSION TECHNOLOGY DIVISION

AEROSPACE TECHNOLOGY DIRECTORATE — NASA Lewis Research Center

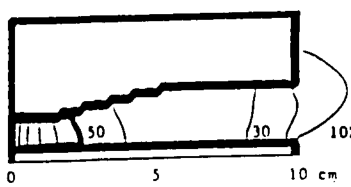
MPD Thruster Modeling

Comparison with Princeton University

Half-Scale Flared Anode Thruster

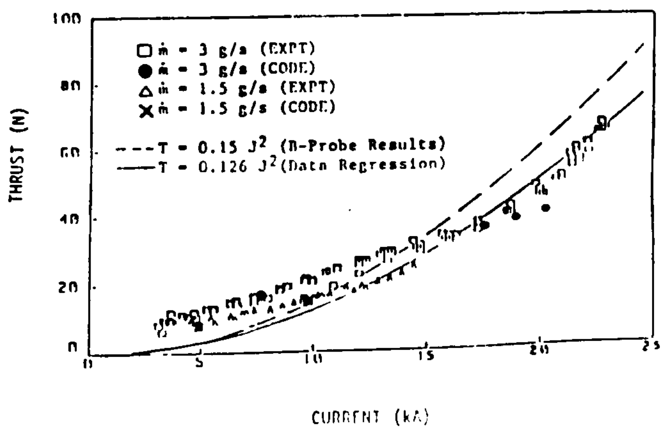


ENCLOSED CURRENT CONTOURS (MEASURED)
7.9 kA, 3 g/s, QUASI-STEADY OPERATION



ENCLOSED CURRENT CONTOURS (PREDICTED)
7.9 kA, 3 g/s, STEADY-STATE OPERATION

Thrust Characteristics



MPD Thruster Modeling

Status

- Self-field version of MPDT code operational
  - Modest execution times 3-5 hours VAX-CPU)
  - General agreement with experimental results
  - Thruster performance evaluations underway
- Applied-field version of code under development
  - Routines for applied-B distributions incorporated
  - Preliminary testing/modification in progress

CD-91-54840

ATD AEROSPACE TECHNOLOGY DIRECTORATE
SPACE PROPULSION TECHNOLOGY DIVISION
NASA
Lewis Research Center

KEY TECHNICAL ISSUES

SPACE PROPULSION TECHNOLOGY DIVISION

NASA Lewis Research Center

KEY SCALING ISSUES

- TWO PRIMARY CONCERNS
  - POWER LEVEL SCALING
  - QUASI-STEADY VS. STEADY STATE

- ISSUES MUST BE ADDRESSED USING
  - THEORETICAL MODELS TO ESTABLISH TRENDS AND DEPENDENCIES
  - HGIH FIDELITY PERFORMANCE MEASUREMENTS
  - DETAILED DIAGNOSTICS OF PLASMA AND ELECTRODE PROCESSES USED TO:
    A. ESTABLISH FUNDAMENTAL RELATIONSHIPS
    B. VERIFY MODELS

SPACE PROPULSION TECHNOLOGY DIVISION

NASA Lewis Research Center

PERFORMANCE EXPECTATIONS:

MUST EVALUATE EFFECTS OF :
- PROPELLANT AND APPLIED FIELD
- ELECTRODE SIZE AND SHAPE
- PROPELLANT INJECTION

RELATION BETWEEN QUASI-STEADY AND STEADY-STATE:

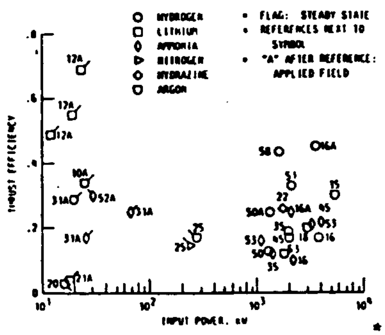
- MUST ESTABLISH DATA BASE WITH CORRECT PROPELLANT IN THE APPROPRIATE OPERATING RANGE ($J^2/\dot{m}$?)
- MUST MEASURE PERFORMANCE, CURRENT DISTRIBUTIONS, PLASMA AND ELECTRODE PARAMETERS

ATD AEROSPACE TECHNOLOGY DIRECTORATE

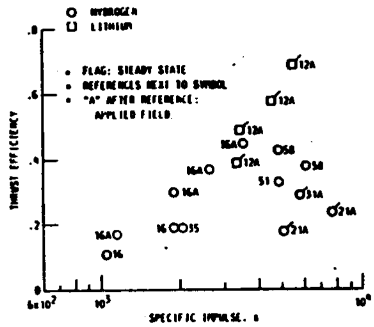
SPACE PROPULSION TECHNOLOGY DIVISION

NASA Lewis Research Center

PERFORMANCE EXPECTATIONS



Thrust efficiency as a function of power and propellant. *



Performance of hydrogen and lithium thrusters.

- NOT CORRELATED WITH POWER
- STRONGLY INFLUENCED BY
  - PROPELLANT CHOICE
  - APPLIED OR SELF-FIELD

* Sovey, J. and Mantenieks, M. "Performance and Lifetime Assessment of Magnetoplasmadynamic Arc Thruster Technology", J. Propulsion and Power, Vol.7, No. 1, Jan-Feb 1991

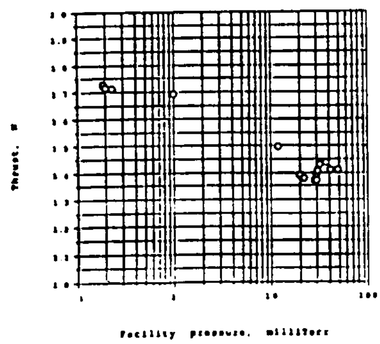
ATD AEROSPACE TECHNOLOGY DIRECTORATE

SPACE PROPULSION TECHNOLOGY DIVISION

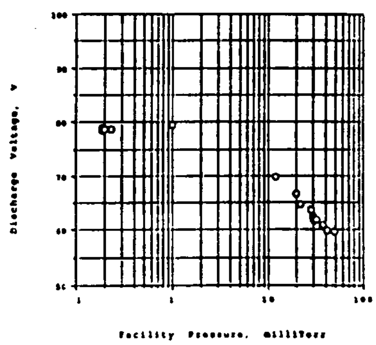
NASA Lewis Research Center

FACILITY REQUIREMENTS

THRUST



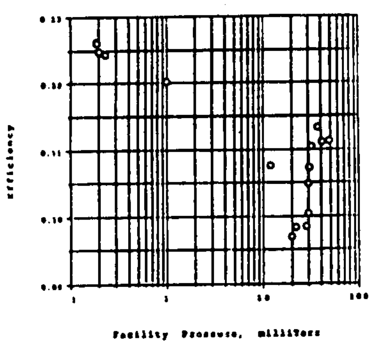
DISCHARGE VOLTAGE



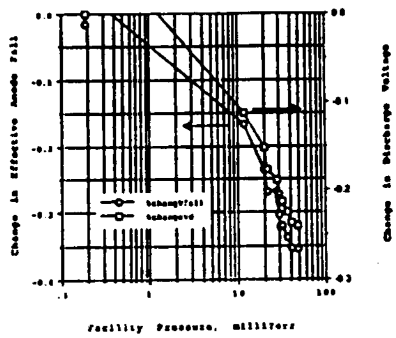
4" D, 3"L ANODE, 0.1 G/S ARGON, 1500 A DISCHARGE, Bz = .1 T

FACILITY REQUIREMENTS

EFFICIENCY



CHANGE IN V_{an} AND V_d



Similar anode heat xfer effect observed by Saber with self-field thrusters

4" D, 3"L ANODE, 0.1 G/S ARGON, 1500 A DISCHARGE, Bz = .1 T

SPACE PROPULSION TECHNOLOGY DIVISION
NASA Lewis Research Center

POTENTIAL MPDT FACILITIES

FY	FACILITY	THRUSTER POWER, MW H2	THRUSTER POWER, MW AR	OPERATION TIME, HR	ESTIMATED COST, $K
PRESENT	LERC T5,T6	0.1 (DEM)	0.22 (DEM)	CONT	-------
1992	LERC T5	0.7-1	1	1 - 2	250 K
1993	LERC T5	1 - 1.5	2	4 - 6	400 K
1995	LERC T6	1 - 1.5	2	'CONT.'	3500 - 5000
1995	LLNL MFTF	1-5		'CONT.'	5000 - 7000
1998	LERC T6	1 - 5	1 - 5	'CONT.'	TBD

SPACE PROPULSION TECHNOLOGY DIVISION

NASA Lewis Research Center

AEROSPACE TECHNOLOGY DIRECTORATE

MATERIAL LIMITATIONS

ANODE:

- MEASURED HEAT FLUX AT HIGH POWER > 5 KW/CM^2 *
  - LITHIUM HEAT PIPES LIMITED TO < 0.5 KW/CM^2
  - OPTIMIZED BEAM DUMP (Cu) LIMITED TO ~ 5 KW/CM^2
  - SSME THROAT HEAT FLUX ~ 16 KW/CM^2 (relevance?)

CATHODE:

- CURRENT DENSITIES AT HIGH POWER > 100 A/CM^2*
  - LONG LIFE CATHODES LIMITED TO CURRENT DENSITIES ≤ 20 A/CM^2 (LOW W.F. TWT CATHODES)

INSULATORS:

- KNOWN TO FAIL AFTER PROLONGED EXPOSURE TO UV AND HIGH TEMPERATURE

- **WE MUST SELECT GEOMETRIES WHERE PERFORMANCE AND ENGINEERING LIMITS CAN BE EVALUATED**

* PRINCETON UNIVERSITY

SPACE PROPULSION TECHNOLOGY DIVISION

NASA Lewis Research Center

AEROSPACE TECHNOLOGY DIRECTORATE

FACILITY LIMITATIONS:

- MUST MEASURE PERFORMANCE AT PRESSURES < 5 X 10^{-4} T
- FACILITY PRESSURE HAS LARGE EFFECT ON ANODE HEAT XFER, NOT CLEAR ON CATHODE

THRUSTER VIABILITY:

- SHOULD FOCUS ON DEVICES WHICH MATCH ENGINEERING LIMITS FOR:
  - ANODE HEAT TRANSFER
  - CATHODE CURRENT DENSITY
  - INSULATOR LIMITS